Modeling of Habitat and Foraging Behavior of Beaked Whales in the Southern California Bight

Simone Baumann-Pickering & John A. Hildebrand
University of California, San Diego
Scripps Institution of Oceanography
9500 Gilman Drive
La Jolla, CA 92093-0205
phone: (858) 534-7280 fax: (858) 534-6849 email: sbaumann@ucsd.edu
phone: (858) 534-4069 fax: (858) 534-6849 email: jhildebrand@ucsd.edu

Tina Yack
Bio-Waves Inc.
144 West D St, Suite 205
Encinitas 92024
phone: (619) 261-1651 fax: (760) 652-4878 email: tina.yack@bio-waves.net

Jeffrey E. Moore
Southwest Fisheries Science Center
NOAA Fisheries Service
8901 La Jolla Shores Drive
La Jolla, CA 92037-1508
phone: (858) 546-7161 fax: (858) 546-7003 email: jeff.e.moore@noaa.gov

Award Number: N00014-12-1-0273
http://baumann.ucsd.edu

LONG-TERM GOALS

The overall goal of this project is to improve our understanding of beaked whale distribution and foraging behavior and to describe inter-specific differences. We are developing habitat models for multiple beaked whale species in the Southern California Bight using passive acoustic encounters. Data from line transect surveys and autonomous recorders are compared with dynamic and static oceanographic habitat variables. We aim to compare habitat models using acoustic line transect data with those generated using autonomous acoustic recorder detections. We intend to model the foraging behavior of beaked whales with respect to spatio-temporal occurrence on a diel or seasonal basis and in correlation to oceanographic or geographic variables.

OBJECTIVES

The objective of this project is to improve our understanding of beaked whale distribution and foraging behavior and to describe inter-specific differences. Knowledge about foraging behavior and habitat preference and potential shifts due to seasonal or oceanographic factors are crucial for conservation and management, as well as mitigation of potential effects for naval activities. Previous experience

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2014**	2. REPORT TYPE	3. DATES COVERED **00-00-2014 to 00-00-2014**

4. TITLE AND SUBTITLE **Modeling of Habitat and Foraging Behavior of Beaked Whales in the Southern California Bight**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of California San Diego,Scripps Institution of Oceanography,9500 Gilman Drive,La Jolla,CA,92093**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**8**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

shows that modeling habitat preference of poorly known species, such as beaked whales, can lead to their visual identification during fieldwork and improved understanding of foraging behavior and habitat preference.

APPROACH

High-Frequency Acoustic Recording Packages (HARPs, Wiggins & Hildebrand 2007) have collected acoustic data at 17 sites within the Southern California Bight (SCB) since 2006. Sites ranged from 200 to 1400 m of depth and were covering a broad range of habitats. Acoustic signal processing for HARP data is performed using the MATLAB (Mathworks, Natick, MA) based custom program Triton (Wiggins & Hildebrand 2007) and other MATLAB custom routines. Data are screened manually and with automated detectors. We compare acoustic encounters of beaked whales with ten different beaked whale type signals known for the North Pacific (Baumann-Pickering et al. 2013) to determine a species label.

Data from acoustic line-transect surveys (2008-2011) carried out by NOAA Southwest Fisheries Science Center (Jay Barlow) in collaboration with Bio-Waves, Inc. (Tina Yack), supplies the second beaked whale data set for the habitat modeling effort. These data were post-processed using PAMGuard Software to verify beaked whale encounters and assign final species identifications to acoustic encounters when possible and when no associated visual encounter occurred (Figure 1).

Foraging bouts are automatically detected by investigating consecutive low inter-click intervals (5-10 ms) and low received levels (~20dB lower than prior FM pulses during search and approach phase) (Madsen et al. 2005, Johnson et al. 2006, Baumann-Pickering et al. 2010). Criteria will have to be established for estimating distance of the animals to the recorder to account for detection probability of a foraging event in an echolocation sequence. The relative abundance of foraging events throughout the SCB will be quantified.

The manual and automatic detection time stamps of HARP data are stored with the remainder of metadata (e.g. project name, instrument location, detection settings, detection effort) in the database Tethys, a workbench for acoustic metadata. The database interacts with outside sources to retrieve physical or biological oceanographic data for habitat model development. The Tethys workbench project is nearing completion under a grant issued through the National Oceanographic Partnership Program (NOPP) to Marie Roch (PI), San Diego State University, with Baumann-Pickering, Hildebrand et al. as co-PIs. We were able to substantially benefit from advances made under the NOPP grant in the management, retrieval, and manipulation of metadata.

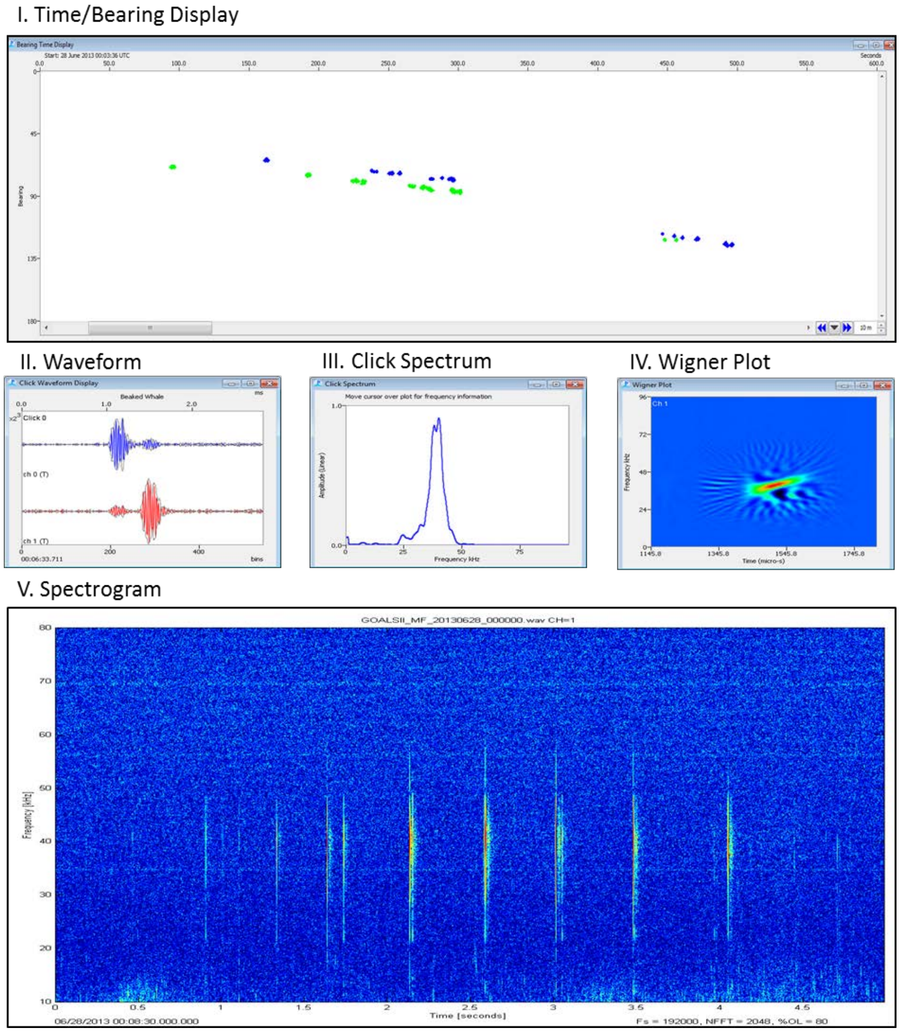

Figure 1. PAMGuard semi-automated species classification of towed array beaked whale encounters. Panel (I) shows echolocation signals detected for the encounter and marked as events with calculated bearing on the y-axis and time along the x-axis (2 individuals are marked in green and blue, respectively). Panel (II) shows the waveform of the selected echolocation signal with amplitude displayed along the y-axis and sample bins (e.g. time) displayed on the x-axis. Panel (III) shows the spectrum display with amplitude on the y-axis and frequency (kHz) along the x-axis. Panel (IV) shows a Wigner plot of the selected echolocation signal. Panel (V) displays the spectrogram of the encounter event with time (seconds) along the x-axis and frequency kHz) along the y-axis (Triton software).

WORK COMPLETED

A multi-step automatic detection routine was run on all HARP data collected between 2006 and 2013 in the SCB, capable of detecting FM pulses from Blainville's, Cuvier's, Stejneger's, and Deraniyagala's beaked whale as well as four signal types of unknown origin (BW40, BW43, BW70, BWC), described in Baumann-Pickering et al. (2013), with approximately 5% missed detection rate,

varying slightly with changes in ambient sound, species composition, and site-specific abundance. Automatic detection for Baird's and Longman's beaked whales has not been successful with the current automated routine. This resulted in detections from long-term data from 141 deployments at 17 sites, a sum of approximately 28 years of recordings in the SCB. Manual inspection of all automatic detections was performed with the help of a machine-assisted classification tool (Baumann-Pickering et al. 2013) to label acoustic encounters to species-level and eliminate false detections.

The towed array data 2008, 2010, and 2011 have been post-processed and final quantifications of beaked whale encounters have been obtained for the datasets. Using a custom routine in R software, the towed array trackline effort was divided into 5 km segments for association with static and dynamic oceanographic variables.

Static oceanographic variables (depth, slope, aspect, and distance to the 1000 and 2000 m isobath) were associated with the HARP deployments and the line-transect segments using ARCGIS 10.1 tools. Propagation modeling using the ESME workbench (Bellhop ray-tracing algorithm) was achieved for all HARP sites to determine a scaling factor for detections based on the area over which detections were collected. Dynamic oceanographic variables (satellite measures: sea surface temperature, sea surface height, sea surface chlorophyll *a*, primary productivity; buoy measures: wind direction and speed, wave direction and speed) were queried through the Tethys workbench from the NOAA ERDDAP service for 8-day averages and these variables were then associated with the HARP and towed array survey points. Mean and standard deviation of these variables was calculated over a polygon at the HARP based on the modeled detection area and over an 8 km square centered on each line-transect segment midway position.

A foraging buzz detector was developed and run over time periods when beaked whales were present. False detections are in the process of being eliminated.

Temporal and spatial patterns of beaked whale presence have been explored for Cuvier's beaked whales and the signal type BW43. Habitat modeling is currently being finalized. Bayesian hierarchical methods will be preferentially applied for accommodating the two acoustic detection data types (HARP and line-transect data). Moreover, Bayesian methods are best suited for obtaining best estimates of habitat relationships rather than basing results on the initial assumption (null models) that there are no relationships between detection data and potential predictor variables.

RESULTS

Analysis of the SCB towed array data resulted in a total of 18 Cuvier's beaked whale encounters, 4 Baird's beaked whale encounters, and 3 unidentified *Mesoplodon* encounters over the 4,875 km of trackline surveyed during the survey years 2008, 2010, 2011 (Figure 2).

The detailed analysis of SCB HARP data resulted in about 103,000 minutes (72 days) with Cuvier's beaked whale acoustic encounters. In contrast, the BW43 FM pulse, likely produced by Perrin's beaked whales (Baumann-Pickering et al. 2014), was detected over about 400 minutes (0.3 days). Cuvier's beaked whale FM pulses were predominantly detected at deeper (>1000 m), more southern, and further offshore sites (in order of relative presence: E, R, H, S, and N, to a lesser degree (<6% relative presence) G2, M, A2, minimally (<1%) P, and A; Figure 3A) within the SCB. The BW43 FM pulse signal in comparison had higher detection rates in the more central basins of the SCB (sites A2, S, N, G2, and H, to a lesser degree (<6% relative presence) E, K3, and G, Figure 3B), indicating a

possible difference in habitat preference and niche separation. It warrants further investigation to determine if this pattern of beaked whale distribution is purely based on bathymetric features or largely driven by water masses within the SCB (e.g. offshore California Current, inshore California Countercurrent, southern edge Ensenada Front) that govern a certain prey species composition and distribution.

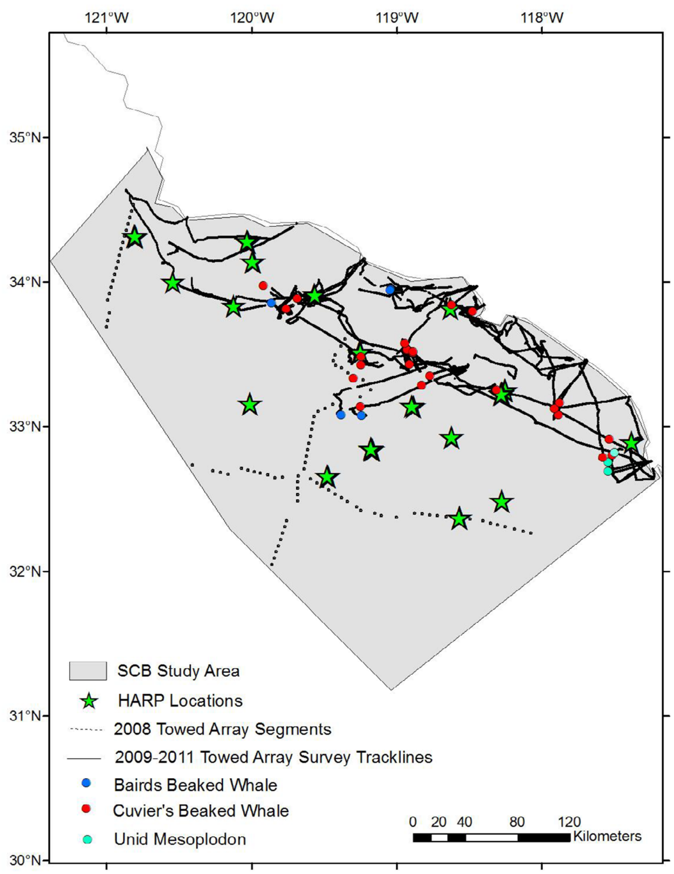

Figure 2: SCB towed array data (black tracklines) from the years 2008-2011 with detections of Baird's (blue), Cuvier's (red), and unidentified beaked whales (turquoise). Grey area denotes polygon over which habitat modeling will be performed.

There appears to be a seasonal pattern to the presence of Cuvier's beaked whales in the SCB at all sites (Figure 4), with generally lower probability of detection during summer and early fall months. However, this may coincide with increased fishing activity and the use of explosives (seal bombs) to deter marine mammals from fishing gear, potentially affecting beaked whale presence in the region. The effect of such anthropogenic activity will have to be taken into account when looking further into seasonal variation.

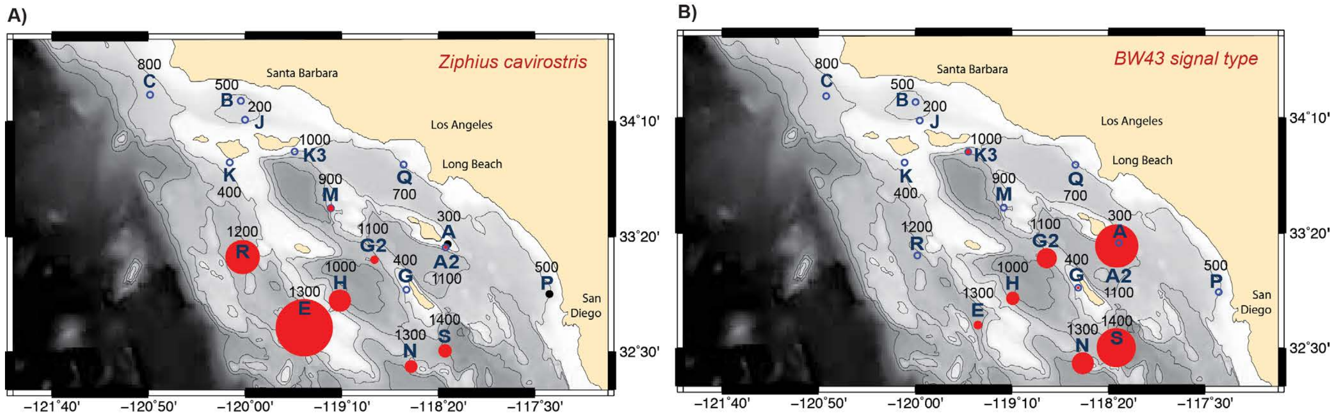

Figure 3: Relative presence (comparison of average daily encounter duration) of A) Cuvier's beaked whale and B) BW43 signal type at 17 sites in Southern California. Blue circles at sites indicate no acoustic encounters; black filled circles in A indicate <1% relative presence.

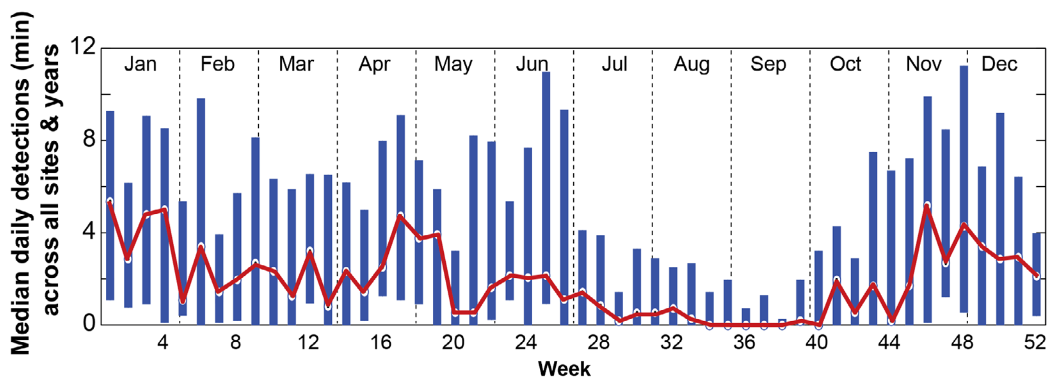

Figure 4: Median daily acoustic encounters (minutes) of Cuvier's beaked whales, across all sites with beaked whale detections and all years monitored (2006-2013) per week, indicating a seasonal presence in Southern California. Red line follows weekly medians. Blue bars are 25th to 75th percentile.

IMPACT/APPLICATIONS

The software tool developed to verify automated classification has proven useful for a variety of projects to date. Habitat models will provide knowledge about foraging and habitat preference and potential shifts due to seasonal or oceanographic factors. This is crucial information for conservation and management as well as mitigation of potential effects of Naval activities, as well as planning for future fieldwork.

TRANSITIONS

The beaked whale FM pulse detector refined within this project is being used for US Navy Fleet range monitoring in SOCAL, NWTRC, GATMAA, MIRC, Cherry Point OPAREA, and JAX.

RELATED PROJECTS

ONR N001210904 Habitat modeling of fin and blue whales in the Southern California Bight. PI Ana Širović and John Hildebrand. The same HARP sites are used for the modeling, but looking at the low frequency range of the acoustic recordings. Efforts in propagation modeling and gathering of external oceanographic data as well as thoughts on modeling methods overlap.

NOPP N00014-11-1-0697 Acoustic Metadata Management and Transparent Access to Networked Oceanographic Data Sets. PI Marie Roch, Co-PI Simone Baumann-Pickering, John A. Hildebrand et al. A metadata management system was developed, which allows access to locally stored acoustic detections and metadata and links in a standardized way to external sources, such as oceanographic or ephemeris data. We were able to benefit from advances made under the NOPP grant in the management, retrieval, and manipulation of metadata.

PACFLT CESU W9126G-13-2-0016 Passive Acoustic Monitoring for PACFLT Naval Training Ranges. PI John Hildebrand and Co-PI Sean Wiggins. Provided support to collect and analyze acoustic data in the Southern California Range Complex.

REFERENCES

Baumann-Pickering S, Wiggins SM, Roth EH, Roch MA, Schnitzler HU, Hildebrand JA (2010) Echolocation signals of a beaked whale at Palmyra Atoll. J Acoust Soc Am 127:3790-3799

Baumann-Pickering S, McDonald MA, Simonis AE, Solsona Berga Aand others (2013) Species-specific beaked whale echolocation signals. J Acoust Soc Am 134:2293-2301

Baumann-Pickering S, Simonis AE, Roch MA, McDonald MAand others (2014) Spatio-temporal patterns of beaked whale echolocation signals in the North Pacific. PLOS One 9:e86072

Baumann-Pickering S, Wiggins SM, Roth EH, Roch MA, Schnitzler HU, Hildebrand JA (2010) Echolocation signals of a beaked whale at Palmyra Atoll. J Acoust Soc Am 127:3790-3799

Johnson M, Madsen PT, Zimmer WMX, Aguilar de Soto N, Tyack P (2006) Foraging Blainville's beaked whales (Mesoplodon densirostris) produce distinct click types matched to different phases of echolocation. J Exp Biol 209:5038-5050

Madsen PT, Johnson M, de Soto NA, Zimmer WMX, Tyack P (2005) Biosonar performance of foraging beaked whales (Mesoplodon densirostris). J Exp Biol 208:181-194

Wiggins SM, Hildebrand JA (2007) High-frequency Acoustic Recording Package (HARP) for broad-band, long-term marine mammal monitoring. International Symposium on Underwater Technology 2007 and International Workshop on Scientific Use of Submarine Cables & Related Technologies, IEEE:551–557

PUBLICATIONS

Baumann-Pickering S, McDonald MA, Simonis AE, Solsona Berga Aand others (2013) Species-specific beaked whale echolocation signals. J Acoust Soc Am 134:2293-2301 [published, refereed]

Baumann-Pickering S, Simonis AE, Roch MA, McDonald MAand others (2014) Spatio-temporal patterns of beaked whale echolocation signals in the North Pacific. PLOS One 9:e86072 [published, refereed]

Baumann-Pickering S, Yack TM, Barlow J, Wiggins SM, Hildebrand JA (2013) Baird's beaked whale echolocation signals. J Acoust Soc Am 133:4321-4331 [published, refereed]

Yack TM, Barlow J, Calambokidis J, Southall B, and Coates S (2013) Identification of previously unknown beaked whale habitat in the Southern California Bight using a towed hydrophone array. J Acoust Soc Am 134:2589-2595 [published, refereed]

ACKNOWLEDGMENTS

US Navy Living Marine Resources, B. Gisiner and F. Stone, US Pacific Fleet, C. Johnson, and Naval Postgraduate School, C. Collins and J. Joseph provided prior and additional funding for data collection and analysis tool develepmont.